IS 2071-3 (1976): Methods of high voltage testing, Part 3: Measuring devices [ETD 19: High Voltage Engineering]

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IS : 2071 ( Part III ) - 1976
( Reaffirmed 2006 )

# Indian Standard

# METHODS OF HIGH VOLTAGE TESTING

## PART III MEASURING DEVICES

## ( First Revision )

Third Reprint MAY 1997

UDC 621.317.326



BUREAU OF INDIAN STANDARDS
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Gr 4

August 1976

# Indian Standard
# METHODS OF HIGH VOLTAGE TESTING
## PART III MEASURING DEVICES
## (First Revision)

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( *Continued from page* 1 )

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# *Indian Standard*

# METHODS OF HIGH VOLTAGE TESTING

## PART III MEASURING DEVICES

## *( First Revision )*

## 0. FOREWORD

**0.1** This Indian Standard ( Part III ) ( First Revision ) was adopted by the Indian Standards Institution on 18 May 1976, after the draft finalized by the High Voltage Techniques Sectional Committee had been approved by the Electrotechnical Division Council.

**0.2** This standard is intended to provide uniform methods of high voltage testing of the electrical equipment.

**0.3** This standard covers the various aspects of high voltage testing, such as definition of the terms, test procedures and requirements of the test objects and the approved measuring devices for dielectric tests with direct voltages, alternating voltages, impulse voltages and impulse currents.

**0.4** The revision of IS : 2070-1962 and IS : 2071-1962 was undertaken in three parts to take into account the rapid advancements in high voltage technology. The Sectional Committee has decided to withdraw IS : 2070-1962 which covered impulse testing.

**0.4.1** This standard, in addition, includes the procedures for carrying out switching impulse voltage test, artificial pollution test and the statistical method of evaluating the test results.

**0.5** This part covers the requirements of the measuring devices. The other two parts of the standard are as follows:

Part I General definitions and test requirements

Part II Test procedures

**0.6** In the preparation of this standard, assistance has been derived from IEC Document 42 ( Central Office ) 24 and 26 Draft High-voltage test techniques — Measuring devices, issued by the International Electrotechnical Commission.

**0.7** In reporting the result of a test made in accordance with this standard, if the final value, observed or calculated, is to be rounded off, it shall be done in accordance with IS : 2-1960*.

*Rules for rounding off numerical values ( *revised* ).

## 1. SCOPE

**1.1** This standard ( Part III ) covers the requirements of measuring devices other than sphere gaps used for the measurement of voltage and currents during dielectric tests with direct voltage, alternating voltage, lightning and switching impulse voltages and for tests with high impulse current.

**1.1.1** Voltage measurements with sphere gaps are covered in IS : 1876-1961*.

NOTE — Specific guidance on measuring systems suitable for these measurements, and on methods for verifying their performance and accuracy are covered in 'Indian Standard application guide for approved measuring devices ( *under preparation* )'.

## 2. TERMINOLOGY

**2.1** For the purpose of this standard, the following definition in addition to those given in Part I of this standard shall apply.

**2.1.1** *Measuring Devices* — Devices which satisfy the requirements specified in this standard.

## 3. GENERAL PRINCIPLES

**3.0** It is generally not practicable to measure high voltages or high impulse currents directly, and the usual procedure is to convert the quantity to be measured to a low voltage or current which can be handled with conventional measuring instruments or oscilloscopes.

Most of the measurements considered in this standard cannot be made with a high degree of accuracy and errors of the order of 3 percent or more shall be tolerated as indicated in the appropriate clauses. Some guidance for evaluating measuring errors is given in 'Indian Standard application guide for approved measuring devices ( *under preparation* )'.

**3.1 Measuring System** — A high voltage or high impulse current measuring system generally comprises:

a) a converting device, for example, a voltage divider, a high voltage impedance or a shunt;

b) the leads required for connecting this device to the test object or into the impulse current circuit;

c) a measuring cable, together with any attenuating, terminating, and adapting impedances or networks ; and

d) the indicating or recording instrument or instruments.

NOTE — Measuring systems which comprise only some of the above components or which are based on different principles are also in use.

*Method for voltage measurement by means of sphere gaps ( one sphere earthed ).

**3.2 High Voltage or High Current Converting Devices** — One of the following converting devices is generally used, depending on the type of voltage or current to be measured.

**3.2.1** *Voltage Divider* — A voltage divider is a device which is intended to produce a suitable fraction of the test voltage for measurement. It usually has two impedances connected in series across which the voltage is applied. One of them, the high voltage arm, takes the major fraction of voltage. The voltage across the other, the low voltage arm, is used for measurement. The components of the two arms are usually resistors or capacitors or combinations of these and the device is described by the type and arrangement of the components.

**3.2.2** *Voltage Transformer* — A voltage transformer is a step-down voltage transformer designed for the measurement of the amplitudes and shapes of high alternating voltages.

**3.2.3** *High Voltage Impedance* — A high voltage impedance is a device which, when subjected to a voltage, passes a current which is intended to be proportional to the voltage when it is connected in series with a current measuring instrument. It consists of resistors or capacitors, or combinations of these but it should not be referred to as a voltage divider although the elements are similar.

**3.2.4** *Current Comparator* — A current comparator is a three-winding magnetic core device of special design. The ratio of the current in two of the windings is to a very high degree of accuracy equal to the inverse of the turns ratio when zero voltage appears across the third winding. Its use is restricted to the determination of the current through a high impedance.

**3.2.5** *Shunt* — A shunt is a resistor which is intended to provide a voltage proportional to the current to be measured. It is usually provided with two pairs of terminals, one pair being used to carry the current to be measured while the other is used for determining the voltage developed across the shunt.

**3.3 Definition of General Terms Related to Measurements**

**3.3.1** *Scale Factor of a Measuring System* — The scale factor of a measuring system is the factor by which the output indication is multiplied to determine the measured value of the input quantity or function. It is in principle a constant but its validity may be restricted to a specific time and frequency range in which case the range for which it is valid shall be stated.

**3.3.2** *Voltage Ratio of a Voltage Divider* — The voltage ratio of a voltage divider is the ratio by which the output voltage is multiplied to determine the measured value of the input voltage. It is dependent on the impedance to earth from the output terminal of the divider and the applicable impedance shall be stated. In principle, the ratio is a constant but its validity may be restricted to a specific time and frequency range in which case the range for which it is valid shall be stated.

**3.3.3** *Response G* — The response *G* of a measuring system is the output as a function of time or frequency when an input is applied to the system.

**3.3.4** *Step Response G ( t )* — The step response *G* ( *t* ) of a measuring system is the response as a function of time *t* when the input is a voltage or current step. A convenient form is the unit step response *g* ( *t* ) in which the output amplitude is denoted as unity when that amplitude, multiplied by the scale factor, equals the input step.

**3.3.5** *Frequency Response G ( f )* — The frequency response *G* ( *f* ) of a measuring system is the ratio as a function of the frequency *f* of the output to the input of the system when the input is a sinusoid. A convenient form is 'the normalized frequency response *g* ( *f* )' in which the output amplitude is denoted as unity when that amplitude, multiplied by the scale factor of the system, equals the input.

**3.3.6** *Response Time T* — The response time *T* of a measuring system is indicative of the errors encountered when measuring rapidly changing voltages or currents. It is defined as:

$$T \simeq \frac{a_i - a_m}{da_m/dt}$$

where

$a_i$ = value of the input function at some specific time; and

$a_m$ = measured value of that quantity, with the provision that the rates of change of both the input function and the measured value of that function are constant and equal.

NOTE — Particulars concerning the response time and related response parameters are given in 'Indian Standard application guide for approved measuring devices ( *under preparation* )'.

**3.4 General Requirements of Measuring Systems** — The measuring accuracy and other characteristics of a measuring system shall comply with the requirements given in **4**, **5**, **6** and **7** according to the type of voltage or current to be measured.

**3.4.1** *Instrument Characteristics* — When instruments of standard types are employed, they should, where applicable, comply with IS : 1248-1968* and should be of class 0·5 or better. Other instruments, such as oscilloscopes and peak voltmeters should comply with the general requirements for measuring systems given in this standard.

*Specification for direct acting electrical indicating instruments ( *first revision* ).

**3.4.2** *Performance Tests* — Compliance with the requirements given in this standard shall be verified by performance tests such as those described in the appropriate clauses of 'Indian Standard application guide for approved measuring devices (*under preparation*)'. The results and the inherent accuracy of these tests shall be stated in a 'record of performance' ( *see* **3.4.3** ), which record should be retained by the user.

**3.4.2.1** The performance tests usually need be made once only, but if the system is modified in any significant respect ( or its performance is in doubt ), they should be repeated in part or in full. For some of the tests, it is sufficient that the test be made on a single proto-type device.

The tests should determine in particular:

a) the scale factor and its stability;

b) the response characteristics ( relevant to the types of voltage or current to be measured );

c) the influence of neighbouring objects, either earthed or at high voltage, on the scale factor and the response. The minimum acceptable clearances to such objects shall thus be determined;

d) the influence of the applied voltage or current amplitude and duration, and of atmospheric conditions and surface pollution, if any, on the measured characteristics; and

e) the ability of the measuring system to operate at its rated maximum voltage or current.

Characteristics (a), (b) and (c) may be determined by tests at low voltage provided that non-linear effects, for example, due to corona, are not involved when the full voltage or current is applied.

**3.4.2.2** In principle the characteristics specified in **3.4.2.1** should be determined for the complete measuring system. They may, however, be deduced from separate tests made on its individual components; when this is done the methods by which they are determined and the results of each of the individual measurements shall be stated in the record of performance.

**3.4.2.3** As an alternative to separately determining the performance characteristics specified in **3.4.2.1** (a) to (e), it is permissible to evaluate the overall performance of a system by direct comparison with that of another system known to have adequate accuracy and response characteristics. This comparison shall be made by simultaneous measurements with both systems, using the type of voltage or current actually to be measured.

**3.4.3** *Record of Performance* — In addition to the results of the tests specified in **3.4.2**, the record of performance shall include a general description of the system, its components, its principal dimensions and other relevant parameters. More specifically, information on the following items should be given when applicable:

a) Details of the type of earth return system and of the connections to it used during the performance tests;

b) The length, diameter and position of the high voltage lead;

c) The type, length and position of the measuring cable;

d) The characteristics of the instruments used while carrying out the performance tests; and

e) The response to high frequency transient oscillations as a function of frequency and ( for impulse measuring systems ) the highest frequency $f_{Max}$ for which the system is suitable.

Furthermore, the record of performance should state the allowable variations of the elements listed above for the application to a specific measurement.

**3.4.4** *Routine Check* — It is recommended that tests should be made periodically, or on request in connection with a particular test, to ensure:

a) that the scale factor of the measuring system has not changed from the value determined in accordance with **3.4.2**, and

b) that the disturbance level is sufficiently low.

## 4. MEASURING SYSTEMS FOR DIRECT VOLTAGE

**4.1 Quantities to be Measured, Accuracies Required and Requirements of the Measuring System** — The general requirements for direct voltage measurement are:

a) to measure the arithmetic mean value of the voltage with an error of not more than 3 percent; and

b) to measure the ripple amplitude with an error less than 10 percent of the actual ripple amplitude or less than 1 percent of the arithmetic mean value of the direct voltage, whichever is the larger.

NOTE — In certain cases, it may be necessary to detect and measure transient components. No requirements for this are given here, but some guidance may be obtained from the clause of ' Indian Standard application guide for approved measuring devices ( *under preparation* ) ' dealing with impulse voltage measurements.

**4.2** These requirements will be met if the system meets the general requirements of **3.4** and the performance tests specified show the following:

a) The voltage ratio of the voltage divider or the value of the series impedance is stable and known with an error of less than 1 percent and the current drawn from the high voltage source is not less than 0·5 mA (*see* Note); and

b) The frequency response of the system used for measuring ripple voltage is adequate and known to within 10 percent for frequencies from the fundamental of the ripple frequency up to five times this frequency.

NOTE — In the case of high impedance systems involving either a voltage divider or series impedance, it may not be possible to comply with (a). In this case, an error of up to 3 percent is permitted if a standard instrument according to **3.4.1** is used for the measurement of the arithmetic mean value, but this may result in the overall error slightly exceeding 3 percent which is still acceptable.

## 5. MEASURING SYSTEMS FOR ALTERNATING VOLTAGES

**5.1 Quantities to be Measured, Accuracies Required and Requirements of the Measuring System** — The general requirements for alternating voltage measurement are:

a) to measure the peak or rms value of the voltage with an error of not more than 3 percent; and

b) to measure the amplitude of harmonics with an error less than 10 percent of the harmonic amplitude or less than 1 percent of the fundamental, whichever is the larger.

NOTE — In certain cases, it may be necessary to measure voltage transients superimposed on an alternating voltage. No requirements for this are given here, but some guidance may be obtained from 'Indian Standard application guide for approved measuring devices (*under preparation*)' dealing with impulse voltage measurements.

**5.2** These requirements will be met if the system meets the general requirements of **3.4** and the performance tests specified show the following:

a) The voltage ratio of the voltage divider or voltage transformer, or the value of the series impedance is stable and known with an error of less than 1 percent; and

b) The frequency response of the system used for measuring harmonics is adequate and known to within 5 percent for frequencies from the fundamental to the *n*th harmonic. For most systems, *n* may be taken as 7. However, for systems depending on measurement of the charging current of a capacitor, higher values ( for example, $n \simeq 20$ ) may have to be considered.

NOTE 1 — In the case of high impedance systems involving a voltage divider or a series impedance, it may not be possible to comply with (a). In this case, an error of up to 3 percent is permitted if a standard instrument according to **3.4.1** is used for the measurement of the rms or peak value of the voltage, but this may result in the overall error slightly exceeding 3 percent which is still acceptable.

NOTE 2 — When a wave analyzer is used for the measurement of individual harmonics, its measuring error should be less than 5 percent for harmonics up to the 7th and less than 10 percent for those up to the 27th.

## 6. MEASURING SYSTEMS FOR IMPULSE VOLTAGES

**6.1 Quantities to be Measured and Accuracies Required** — Practical difficulties prevent the attainment of the same degree of accuracy of measurement for all types of impulse voltages. Consequently, the accuracy requirements for a measuring system are specified in terms of the type of impulse to be measured.

**6.1.1** The general requirements for impulse voltage measurement are the following:

a) to measure the peak value of full impulses and impulses chopped in the vicinity of the crest or on the tail with an error not exceeding 3 percent.

b) to measure the peak value of impulses chopped on the front with an error $\Delta$ which is dependent on the time to chopping $T_c$ as follows:

   if $T_c > 2\ \mu s$, $\Delta \leqslant 3$ per cent

   If $0{\cdot}5\ \mu s \leqslant T_c \leqslant 2\ \mu s$, $\Delta \leqslant 5$ percent

   if $T_c < 0{\cdot}5\ \mu s$, $\Delta > 5$ percent permissible ( the upper limit is not at present defined ).

c) No general guidelines are given to measure the time parameters which define the impulse shape, in case a measuring error not exceeding 10 percent is desired. For the time defining the duration of voltage collapse in a chopped impulse, no specification of accuracy is given because of the extreme difficulty in its measurement.

d) Also, no general guidelines are given to measure the oscillations on an impulse with sufficient accuracy to ensure that they do not exceed the permitted levels given in **4.2.2** of IS : 2071 ( Part II )-1974*.

*Methods of high voltage testing: Part II Test procedures.

**6.2 Classification of Impulse Measuring Systems**

**6.2.1** Measuring systems for impulse voltages are classified according to the number of components in the high voltage part of the system. One, two and three component systems are in use but the two component system is the most common. The relevant components are:

a) the voltage divider,

b) the high voltage lead, and

c) any damping resistor at the *input end* of the high voltage lead.

NOTE — If the damping resistor is used at the divider end of the high voltage lead, it is treated as part of the divider and the system is then a two component system.

**6.2.2** The record of performance should state specifically the type of system, the length of high voltage lead and value of damping resistor ( if any ) used in determining the response characteristics.

The following additional components normally complete the measuring system:

a) A coaxial cable for transmitting the low voltage output to a measuring instrument ( this cable usually forms a part of the low voltage arm of the divider ),

b) An oscilloscope or a peak voltmeter or both, and

c) An earth return system.

NOTE — When testing with full standard lightning or switching impulses, if previous experience with the particular test equipment and test object has indicated that the shape of the impulse is satisfactory, a peak reading instrument designed specifically for impulse measurements may be used instead of the oscilloscope to measure the peak value. Such instruments should be recalibrated frequently. Alternatively, such impulses may be measured with a sphere gap ( *see* IS : 1876-1961* ).

**6.3 Requirements of Measuring Systems** — The requirements of **6.1** will be met if the system meets the requirements of **3.4** and the performance tests specified show that the requirements of **6.3.1** and **6.3.2** are satisfied.

**6.3.1** *Accuracy of the Scale Factor*

**6.3.1.1** The voltage ratio of the voltage divider should be stable and known with an error not exceeding 1 percent.

NOTE — In general, when dividers of the capacitive type are connected to an oscilloscope or peak voltmeter, the divider ratio will not be constant for the whole duration of the impulse if that duration is very long. It is sufficient for the ratio to be constant to within 1 percent for the time required for the impulse being measured to reach its peak value, provided that it is also constant to within 5 percent up to the time to half value of the longest impulse to be measured.

*Method for voltage measurement by means of sphere gaps ( one sphere earthed ).

**6.3.1.2** The voltage scale factor of the oscilloscope or peak voltmeter ( including attenuators or coupling devices ) should be stable and known with an error not exceeding 2 percent.

**6.3.1.3** The time scale of the oscilloscope should be stable and known to within 2 percent.

**6.3.2** *Response Requirements*

**6.3.2.1** The response time requirements for measuring systems depend on the impulse shapes to be recorded, as shown in Table 1.

**TABLE 1 RESPONSE REQUIREMENTS FOR IMPULSE VOLTAGE MEASUREMENT**

| Impulse to be Measured | Requirement |
|---|---|
| (1) | (2) |
| Full standard 1·2/50 lightning impulse and lightning impulses chopped on the crest or tail | $\mid T \mid \leqslant 0{\cdot}2\ \mu s$ |
| Linearly rising chopped lightning impulses, rise time $T_R$ | $\mid T \mid \leqslant 0{\cdot}5\ T_R$ and $\leqslant 0{\cdot}2\ \mu s$ |
| Non-linearly rising lightning impulses chopped at $T_c$ | $\mid T \mid \leqslant 0{\cdot}5\ U_{Max}/S_L$ ( *see* Note 2 ) |
| All switching impulses | $\mid T \mid \leqslant 0{\cdot}03\ T_c$ and $\leqslant 0{\cdot}03\ T_{cr}$ ( *see* Note 3 ) |

NOTE 1 — Definitions of $T_R$, $T_c$ and $T_{cr}$ are given in IS : 2071 ( Part II )-1974*.

NOTE 2 — A non-linearly rising impulse is to be approximated by a number of closely fitting straight lines. Provided the chopping is rapid and the last straight line covers 10 percent or more of the front, the slope of this line $S_L$, together with the measured crest value $U_{Max}$ is used to determine the requirement on $\mid T \mid$. No information can be given relating to the error in the measurement of $T_c$. For impulses not fitting into the above category, some guidance is given in the impulse clause of 'Indian Standard application guide for approved measuring devices ( *under preparation* )'.

NOTE 3 — For the measurement of partial discharges during switching impulses, the response time of the measuring system should be considerably better than that given above but no specifications can be given at present.

*Methods of high voltage testing: Part II Test procedures.

The above limits, if entirely utilized, may produce the maximum permitted error without considering other types of errors. It is recognized that under these conditions, the total error may exceed that specified in **6.1**.

The response time $T$ generally results in a systematic error, both in the measurement of the time parameters of an impulse and in the measurement of amplitudes of impulses chopped on the front. Since, however, there is also a random error in the determination of the value of $T$, this gives an additional random component of error in the measurement of the above parameters.

**6.3.2.2** The response of a measuring system to transient oscillations superimposed on an impulse depends on the frequency of the oscillation and on the shape of the step response of the system. It is recognized that in general the transient oscillations cannot be recorded with great accuracy. Therefore, corrections shall be made to the recorded amplitudes when necessary and the corrected values of the oscillation amplitudes shall then be known to within ±20 percent of the maximum permitted values.

In order to ensure that the requirements of **6.1** for measurement of oscillations are met, it is necessary that the required correction factor for recorded oscillations shall not exceed 5 for any frequency up to $f_{Max}$ ( *see* **6.4** ). One recognized method of determining the correction factor is given in 'Indian Standard application guide for approved measuring devices ( *under preparation* )'.

**6.4 Maximum Frequency to be Recorded,** $f_{Max}$ — The maximum frequency to be recorded is the highest oscillation frequency which may appear at the test object or at the high voltage input terminal of the measuring system, in a given test circuit, with sufficient amplitude to affect the shape of the impulse. A conservative value for this is given by:

$$f_{Max} = \frac{c}{4\,(H_g + H_c)}\ MHz$$

where

$c$ = 300 m/μs — the velocity of an electromagnetic wave,

$H_g$ = the height in metres of the portion of the impulse generator being used, and

$H_c$ = the height in metres of the front capacitor.

NOTE — In the case of impulse generating circuits employing a very high series resistance as used when generating switching impulses, oscillations of the above frequency are unlikely to occur. In such cases, the maximum frequency may be taken as 0·1 of the above value. This also applies when the switching impulses are generated by means of a transformer.

## 7. MEASURING SYSTEMS FOR IMPULSE CURRENTS

### 7.1 Quantities to be Measured, Accuracies Required and Requirements on the Measuring System

**7.1.1** The general requirements for impulse current measurement are:

a) to measure the peak value of standard current impulses with an error of not more than 3 percent,

b) to measure the time parameters of impulse currents with an error of not more than 10 percent, and

c) to permit the detection of oscillations superimposed on a current impulse.

**7.1.2** These requirements will be met if the system meets the general requirements of **3.4** and the performance tests specified show the following:

a) The resistance of the shunt or alternatively the ratio of the current transformer or the value of the mutual inductor is stable and known with an error of not more than 1 percent;

b) The response time of the system complies with the requirements set out in Table 2; and

c) The time to half value of the response is considerably longer than the front time and time to half value of the current to be measured.

NOTE 1 — Shunts should preferably be of the tubular type described in 'Indian Standard application guide for approved measuring devices ( *under preparation* )'. Shunts of other types may be used if they are shown to fulfil the above requirements.

NOTE 2 — Guidance on methods for determining the response of shunts is given in 'Indian Standard application guide for approved measuring devices ( *under preparation* )'. The unit step response characteristics of shunts does not in general take the form of a damped oscillation.

**TABLE 2 RESPONSE REQUIREMENTS FOR IMPULSE CURRENT MEASUREMENTS**

| IMPULSE TO BE MEASURED | REQUIREMENT |
|---|---|
| 8/20 | $\lvert T \rvert \leqslant 1{\cdot}6\ \mu s$ |
| 4/10 | $\lvert T \rvert \leqslant 0{\cdot}8\ \mu s$ |

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| T.C. No. 14/1421, University P. O. Palayam, THIRUVANANTHAPURAM 695034 | 6 21 17 |

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|---|---|
| *Sales Office is at 5 Chowringhee Approach, P.O. Princep Street, CALCUTTA 700072 | 27 10 85 |
| †Sales Office is at Novelty Chambers, Grant Road, MUMBAI 400007 | 309 65 28 |
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**Reprography Unit, BIS, New Delhi, India**